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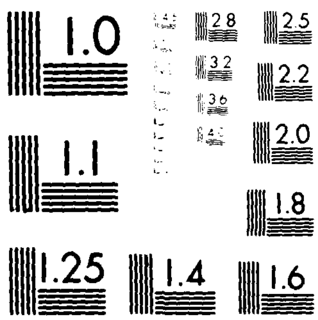

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EVALUATION OF DUAL DRUM VIBRATORY ROLLERS FOR RAPID RUNWAY REPAIR

EDGAR F. ALEXANDER
R. WILLIAM GRAHN
ENGINEERING RESEARCH DIVISION
RAPID RUNWAY REPAIR BRANCH (RDCR)

MARCH 1981

FINAL REPORT

AUGUST 1980 TO NOVEMBER 1980

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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Two dual-drum vibratory rollers were evaluated and compared to the standard Air Force single drum roller. The rollers were evaluated for their ability to compact graded crushed limestone and their ability to reduce the time required to compact crushed limestone for use in runway repair. The repair was tested with F-4 load cart traffic. It was determined that an equal weight dual-drum roller can compact limestone as well as the present Air Force single drum roller and do the job in 50%-60% less time.

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PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall Air Force Base, Florida under Job Order Number 26212006, Bomb Damage Repair Equipment Evaluations. Data from this test resulted in specifications for dual drum vibratory compactors for the new Air Force Rapid Runway Repair equipment kits. This work was done during the period from August 1980 to November 1980.

This report discusses the use of dual drum self-propelled vibratory compactors for bomb damage repair. The report does not constitute an indorsement or rejection of any specific piece of equipment for Air Force use nor can it be used for advertising a product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

BACKGROUND

Military aircraft depend heavily on high quality runways and taxiways for operations. This dependency makes the airfield a prime target for enemy attack. Following an airbase attack, the rapid repair of damaged runways is critical. This urgent requirement has led to the Rapid Runway Repair (RRR) Program, a research and development program of the Air Force Engineering and Services Center (AFESC), Tyndall AFB, Florida.

Work done in the past (Reference 1) has indicated that large vibratory compactors can compact two feet surface of crushed limestone sufficiently to support F-4 aircraft wheel loads. The vibratory compactors use static machine weight plus dynamic force from revolving eccentric weights within the drums to densify materials. All past evaluations have been done using single-drum compactors. If dual-drum vibratory compactors could be used to achieve the same density as single drum compactors, a substantial savings in repair compaction time is possible. The time savings would be due to the double coverage effect for each pass of the dual-drum type machine.

OBJECTIVE

The objective of this test program was to evaluate the performance of two sizes of dual-drum vibratory compactors for use in the rapid repair of weapon-damaged runways. The performance of the dual-drum compactors was compared to that of the 10-ton single-drum compactor, a Raygo 410A, currently designated for use in rapid runway repair.

APPROACH

Field tests and analyses were conducted to meet the objective of this test program. Two dual-drum, self-propelled vibratory compactors were rented for evaluation. A three-phase test program was conducted.

In Phase I the rented dual-drum compactors, plus our own single-drum compactor, were used to compact 24 inches of crushed limestone at the small crater test facility on Tyndall AFB. The parameters monitored during the compaction test were material density and moisture content, with respect to the number of passes of the compactors, and working travel speed.

Phase II consisted of the large dual-drum compactor being tested on the explosive crater test facility on Tyndall AFB. The compactor was used to grade and compact a crater which had

been filled with crushed limestone. The time required for the machine to change lanes was measured during this phase.

Phase III looked at travel speed and the time needed to change drums. The large dual-drum compactor and the single-drum compactor were timed while traveling a preset course. The pad drums on the small dual-drum compactor were changed to smooth drums, the time and difficulty of the change being noted. Calculations were done to estimate the time required for the different machines to compact typical craters.

A representative from Pettibone Corporation, Richard Kerr, Prototype Manager, was present for the evaluation, and participated in all phases of the equipment tests.

The results from this evaluation and other sources were used to determine if dual-drum vibratory compactors are suitable for use in a rapid runway repair equipment kit.

SECTION II

DESCRIPTION OF TESTS

TEST AREAS

The evaluation was conducted at the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

For Phase I compaction tests, the #2 test pit at the Small Crater Test Facility was used (Figure 1). The test pit was filled with clay to 24 inches below the concrete surface. Limestone was then filled to six inches above the concrete surface. The pit was marked off into three traffic lanes, one for each roller. Figure 2 shows the plan and profile of the test pit.

The performance test was conducted at the Explosive Crater Test Facility. A previously repaired crushed limestone crater was scarified to a depth of 2.5 feet. The intent was to make the crater appear to be at the initial grading stage in a crushed limestone repair.

The travel speed test was done over a 2.75 mile course. The lane change time tests were done during the performance tests at the explosive crater test pad site.

MACHINES

This evaluation was conducted using three machines, a Raygo 410A single-drum vibratory compactor, Pettibone C-44 and C-33 dual-drum vibratory compactors.

The Air Force has bought 51 Raygo 400As for use in rapid runway repair. The Raygo 400As are to replace the present towed vibratory compactor. (See Figure 3.) The machines are the same as the Raygo 410A used in this evaluation except that the 410As have drum drive as well as the wheel drive of the 400As. The 10-ton 410A was compared to the two dual-drum compactors. The large Pettibone machine was a 10-ton model C-44, the small Pettibone machine was a 4-ton model C-33. The summary of the manufacturer's specifications for all four machines is contained in Table 1. Complete specifications are contained in Appendix A.

We had originally sought to compare 10-ton dual-drum compactor with our single-drum 10-ton Raygo 410A. The Pettibone Corp. of Fairfield, New Jersey, however, requested that we also test their small 4-ton compactor as they felt the machine might do the job. The three rollers are shown in Figures 4, 5, and 6.

SOILS IN COMPACTION TEST

The clay used in the test pit was local clay, selected to resemble the subgrade found at NATO airbases in northwest Europe. The clay had the following characteristics:

Gradation: See Figure 7.
Specific Gravity: 2.61
Liquid Limit: 65 percent
Plastic Plasticity Index: 41 percent
Unified Soil Classification: CH
Maximum Dry Density (Modified AASHO): 113 pcf
Optimum Moisture Content: 14.5 percent

The crushed limestone used in the compaction test phase had the following characteristics:

Gradation: See Figure 7.
Specific Gravity: 2.76
Liquid Limit: Nonplastic
Plasticity Index: Nonplastic
Unified Soil Classification: SP-SM
Maximum Dry Density (Modified AASHO): 147.2 pcf
Optimum Moisture Content: 5.7 percent

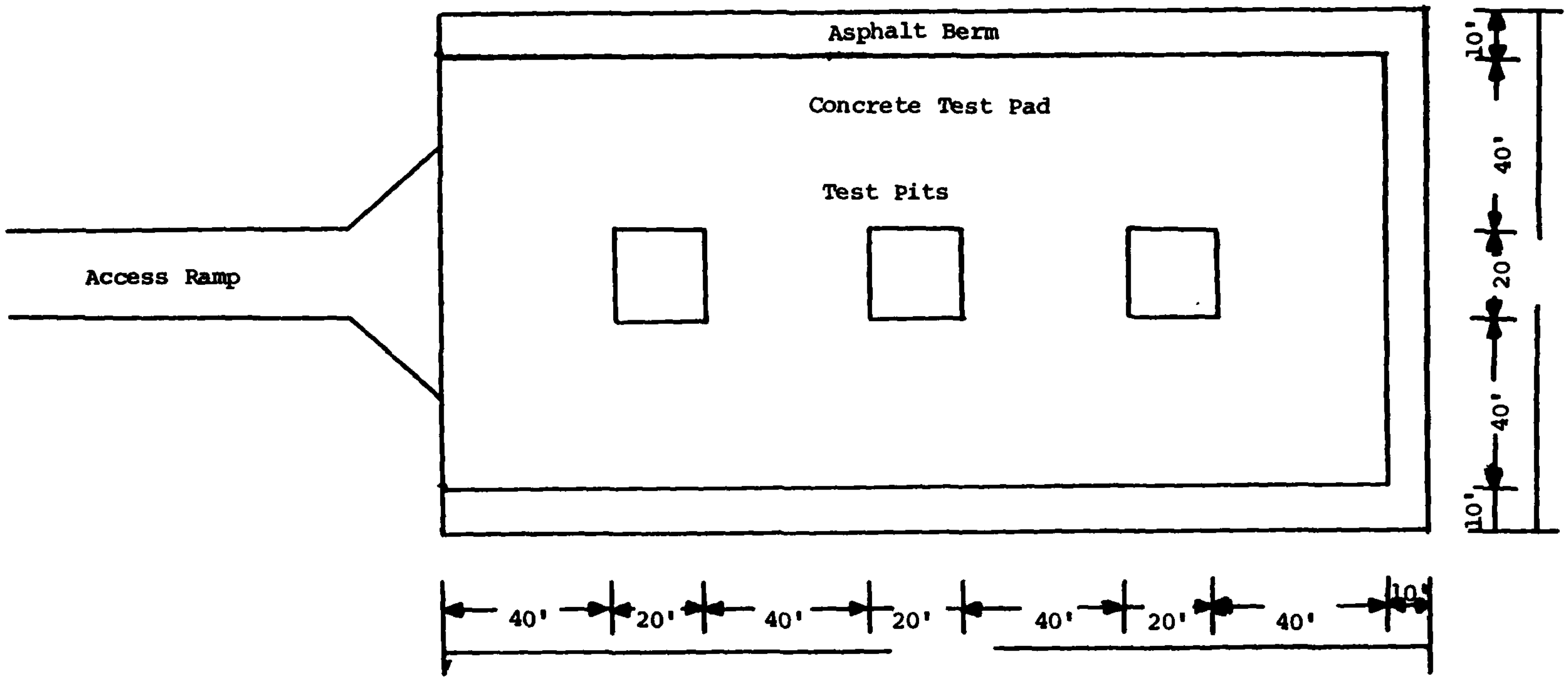


Figure 1. Plan View of Small Crater Test Facility.

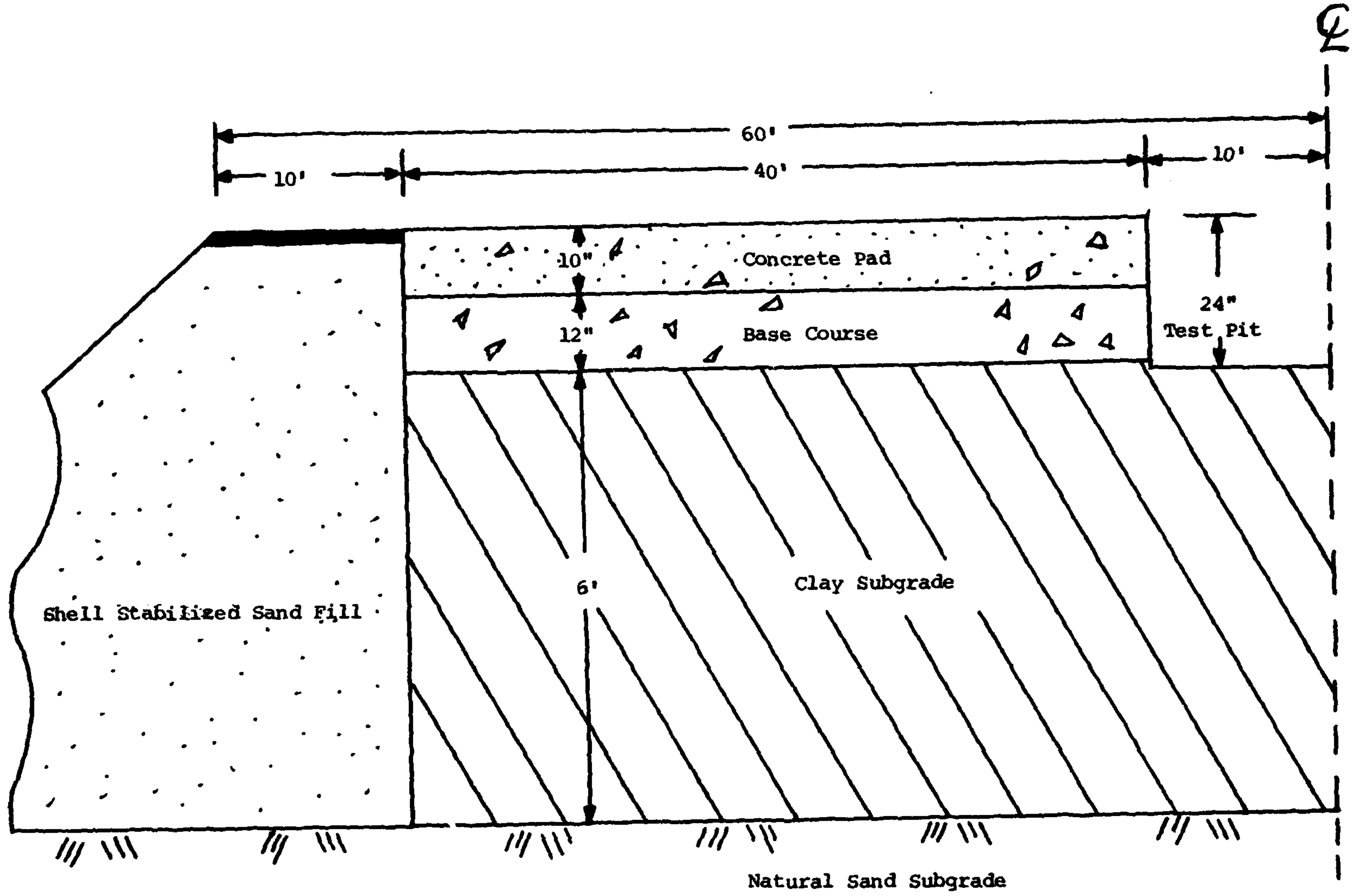


Figure 2. Small Crater Test Facility Half Cross Section.

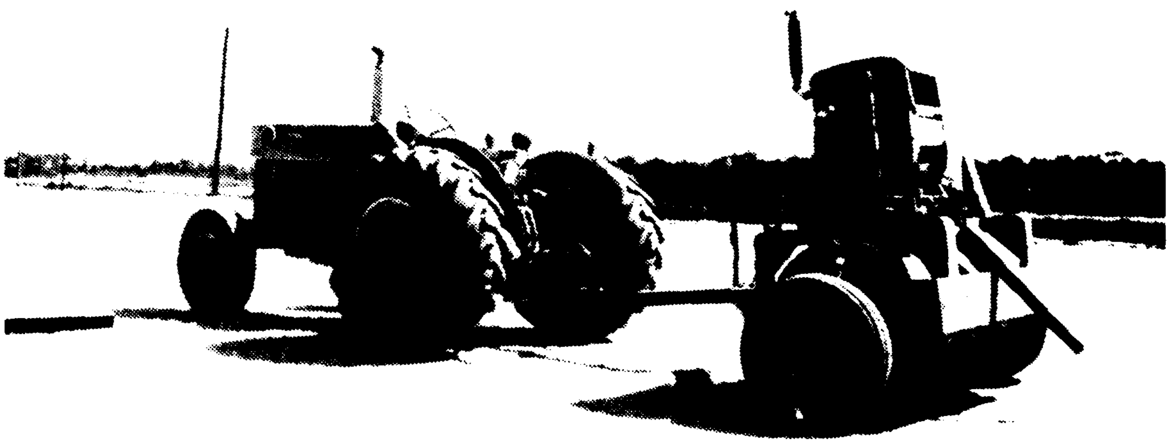


Figure 3. Present Towed Vibratory Compactor

TABLE 1. VIBRATORY COMPACTOR CHARACTERISTICS

	RAYGO 400-A	RAYGO 410-A	PETTIBONE C-44	PETTIBONE C-33
Machine Operating Weight-lbs	20,400	21,800	22,800	7550
Drum Weight	11,000	11,200	11,400	3775
Drum DIA-IN	59	59	49.5	31
Drum Width-IN	84	84	68	42
Rated Dynamic Force (lbs)	27,000	27,000	26,700/drum	6400/drum
Total Applied Force (lbs)	38,000	38,200	38,100/drum	10.175/drum
lbs/Linear in.	452	455	560	242
TRAVEL SPEED	17mph	8mph	6mph	4.5mph

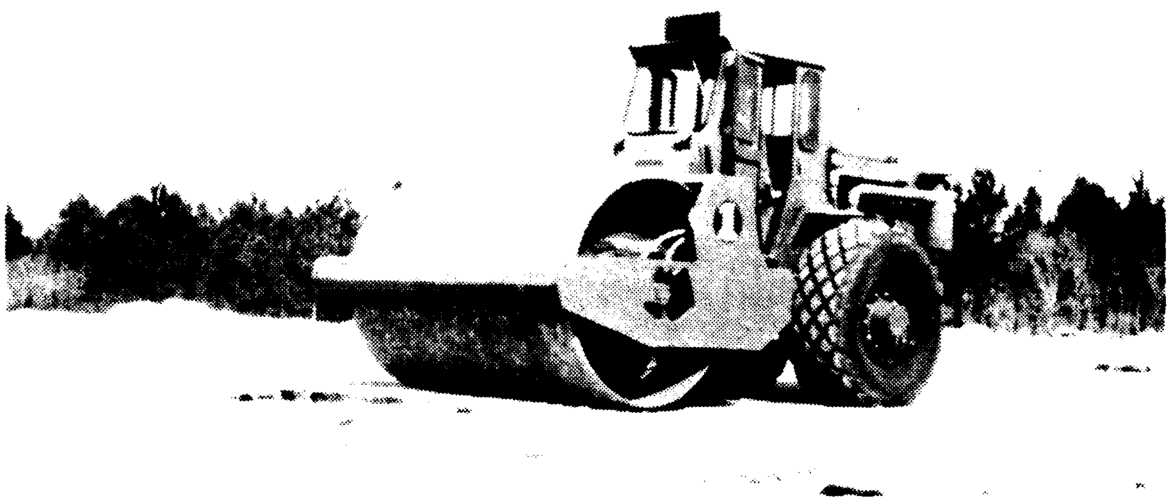


Figure 4. Raygo 410A

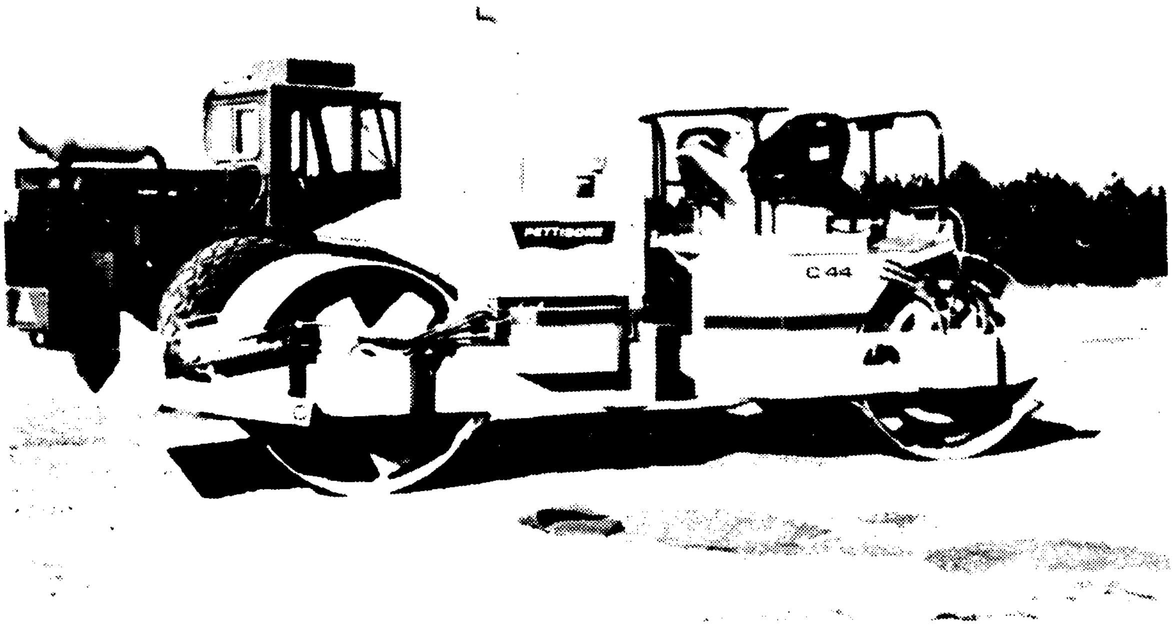


Figure 5. Pettibone C-44

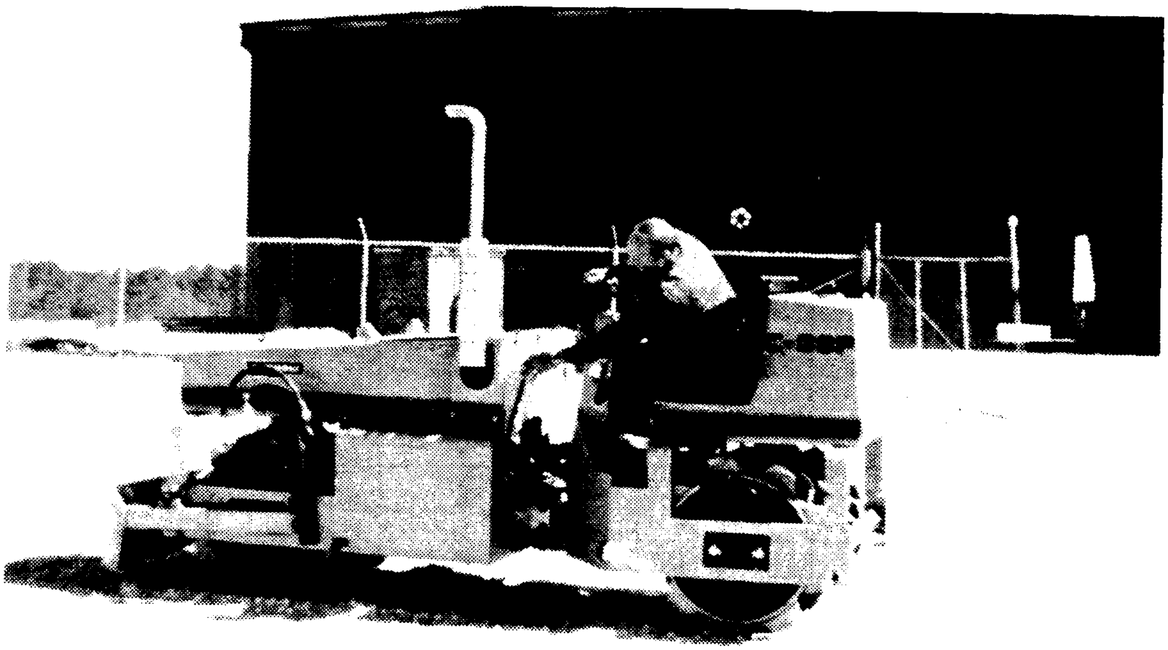


Figure 6. Pettibone C-33

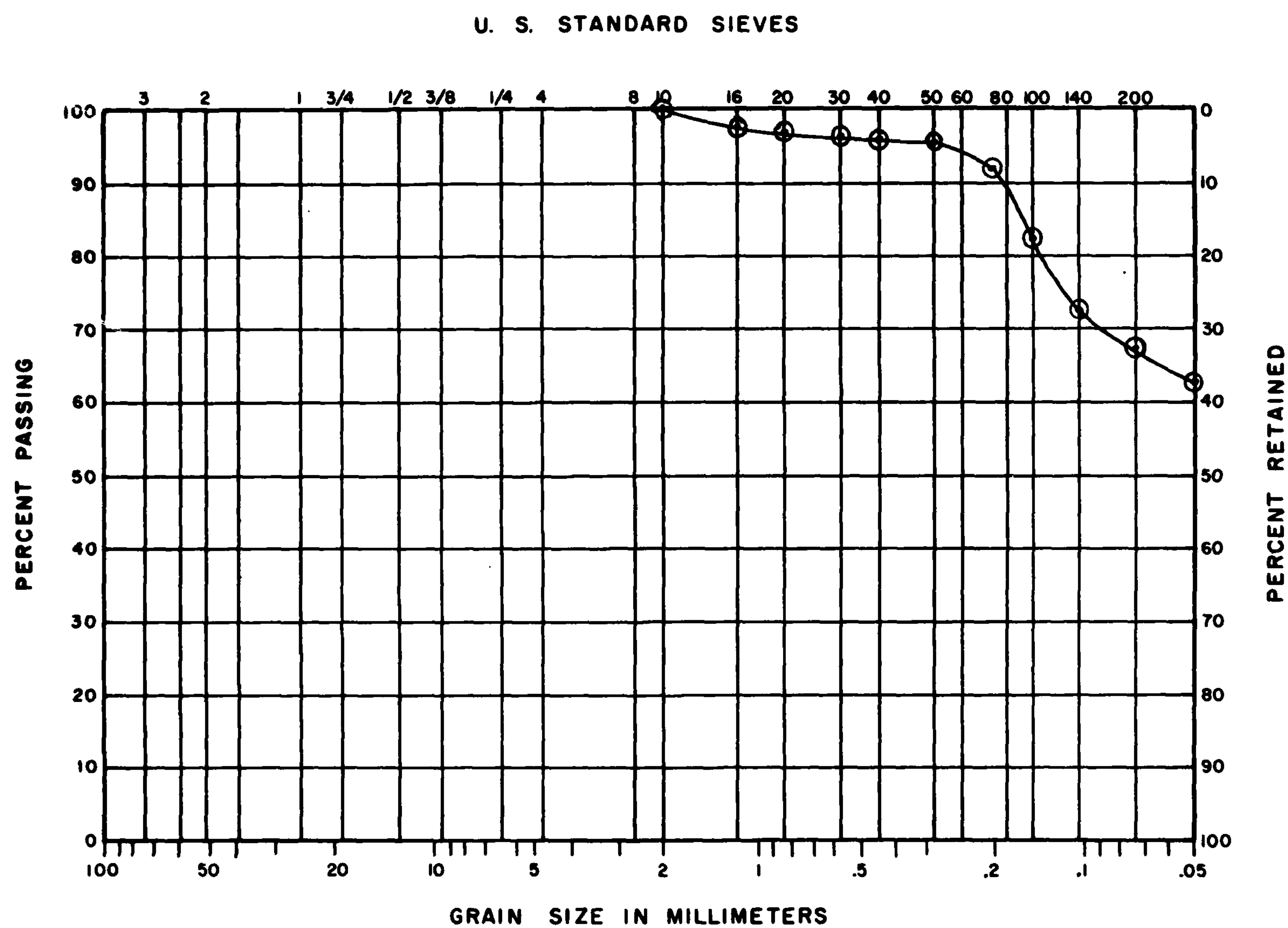


Figure 7. Gradation of Wewahitchka Clay.

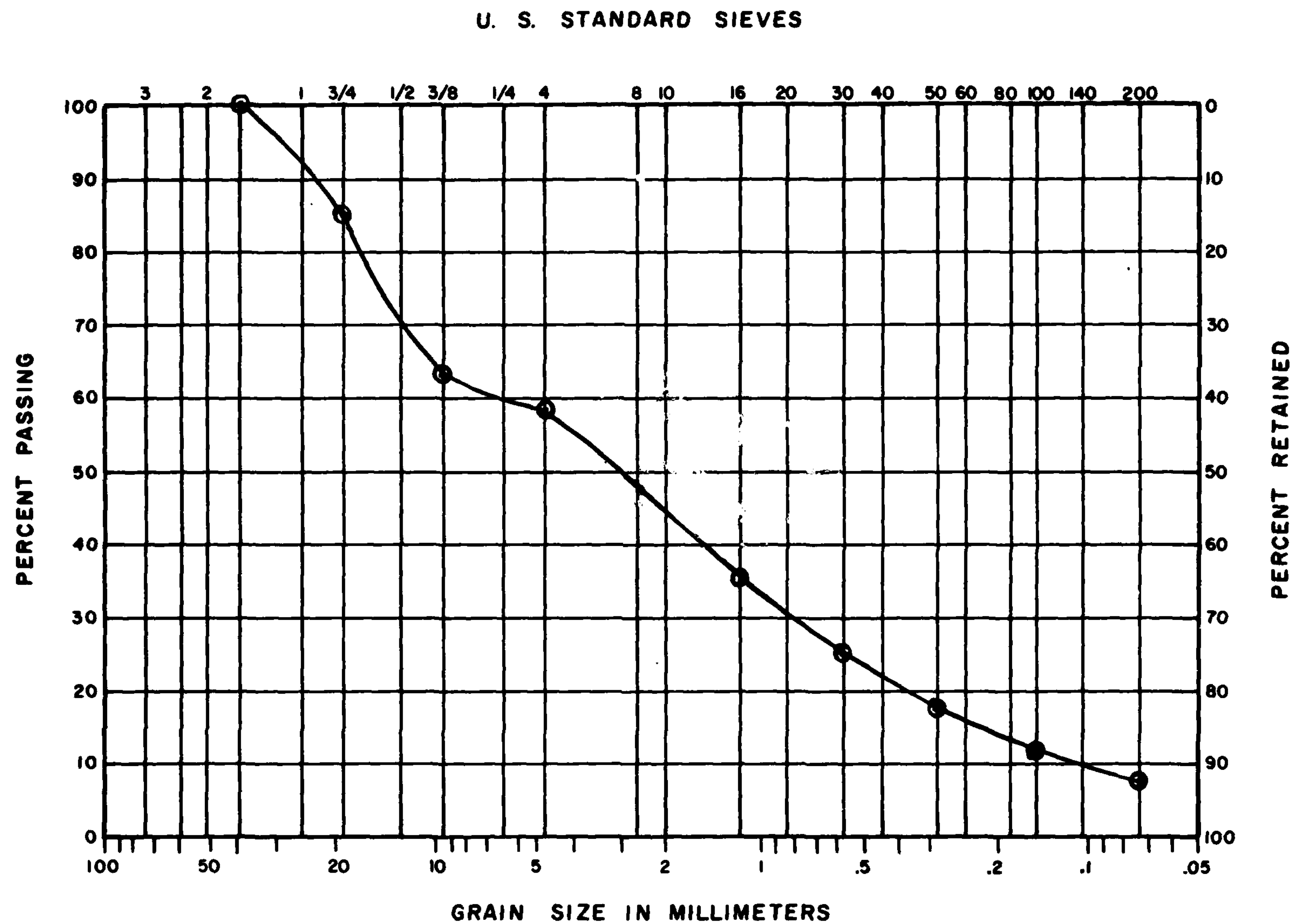


Figure 8. Gradation of 1 1/2" Crushed Limestone.

SECTION III

FIELD TESTS

PHASE I - COMPACTION TESTS

Pit Preparation - The pit had a clay core with a California Bearing Ratio of 3.3, extending from the 2 foot level to 8 feet below the surface of the concrete. The crushed limestone was placed into the pit to a height of 6 inches above the concrete. Three traffic lanes were marked out, one for each compactor. At the start of the tests, before any compaction, the limestone had a moisture content of 4 percent and a loose dry density of 107.0 pounds/ft^3.

Compaction - The test was conducted in two parts. In the first part the two large compactors (Raygo 410A and Pettibone C-44) were used, the small Pettibone C-33 was used in the second part. Each machine compacted a lane of limestone the width of its drums (see Figure 9). Density and moisture content were measured at four-inch and twelve-inch depths using a Troxler Model 3411B nuclear density gauge. The measurements were taken at 0, 4, 8, 12, 16, 20, 24, 26, 28, and 32 coverages of the limestone by the compactors.

The 410A was operated at full throttle to attain its maximum freqency of 1500 vibrations per minute. The machine has one fixed amplitude setting. Travel speed was kept at approximately 4.4 ft/sec throughout the test. This speed is an average working speed for all the machines and was maintained in order to have a consistent speed for all three compactors.

The C-44 was operated at full throttle, which gave 2400 vibrations per minute, and at the maximum amplitude setting. All water ballast tanks were filled before the tests. The travel speed was also kept at 4.4 ft/sec throughout the test. With its dual drums the Pettibone could complete four coverages in half as much time as the Raygo 410A.

The Pettibone C-33 was operated at maximum throttle and amplitude, which resulted in a drum frequency of 3200 vibrations per minute. The water ballast tanks were filled. The travel speed was kept to approximately 4.4 ft/sec.

Data Analysis - Appendix B contains the Troxler density and moisture data. The compaction curves for the Pettibone C-44 and the Raygo 410A showed that the two rollers compact virtually the same. (See Figure 10). The compaction curve for the Pettibone C-33 shows that it cannot reach the high density required. This rules out the smaller machine for use in the RRR kits.

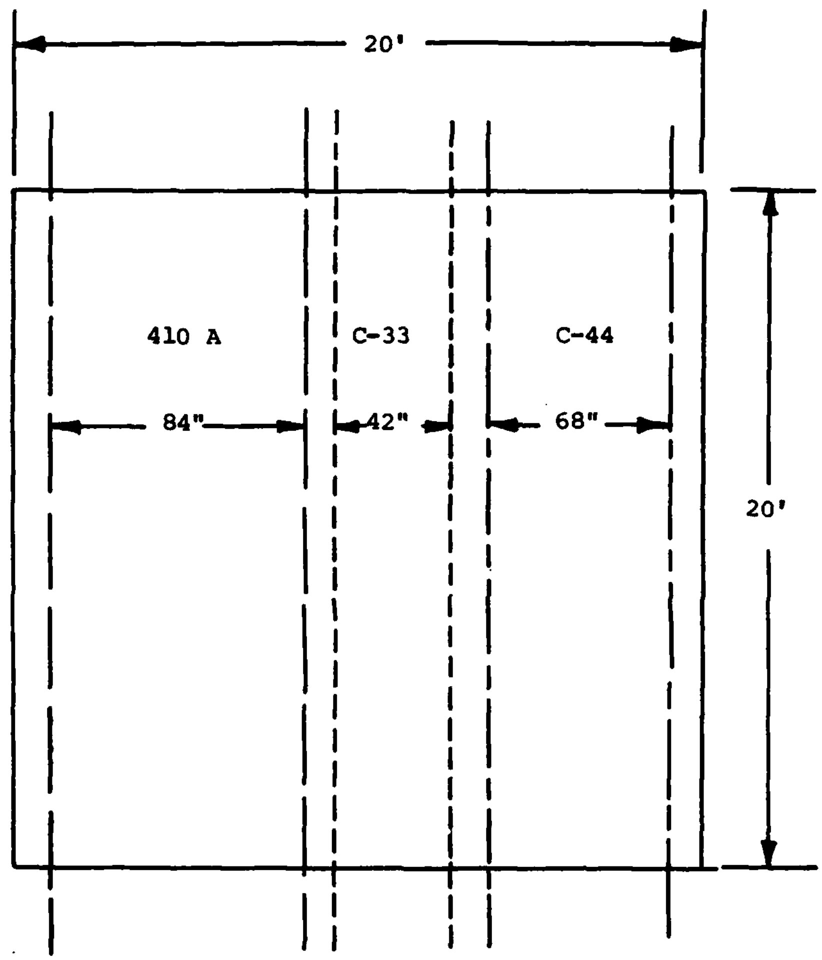


Figure 9. Compaction Test Traffic Lanes.

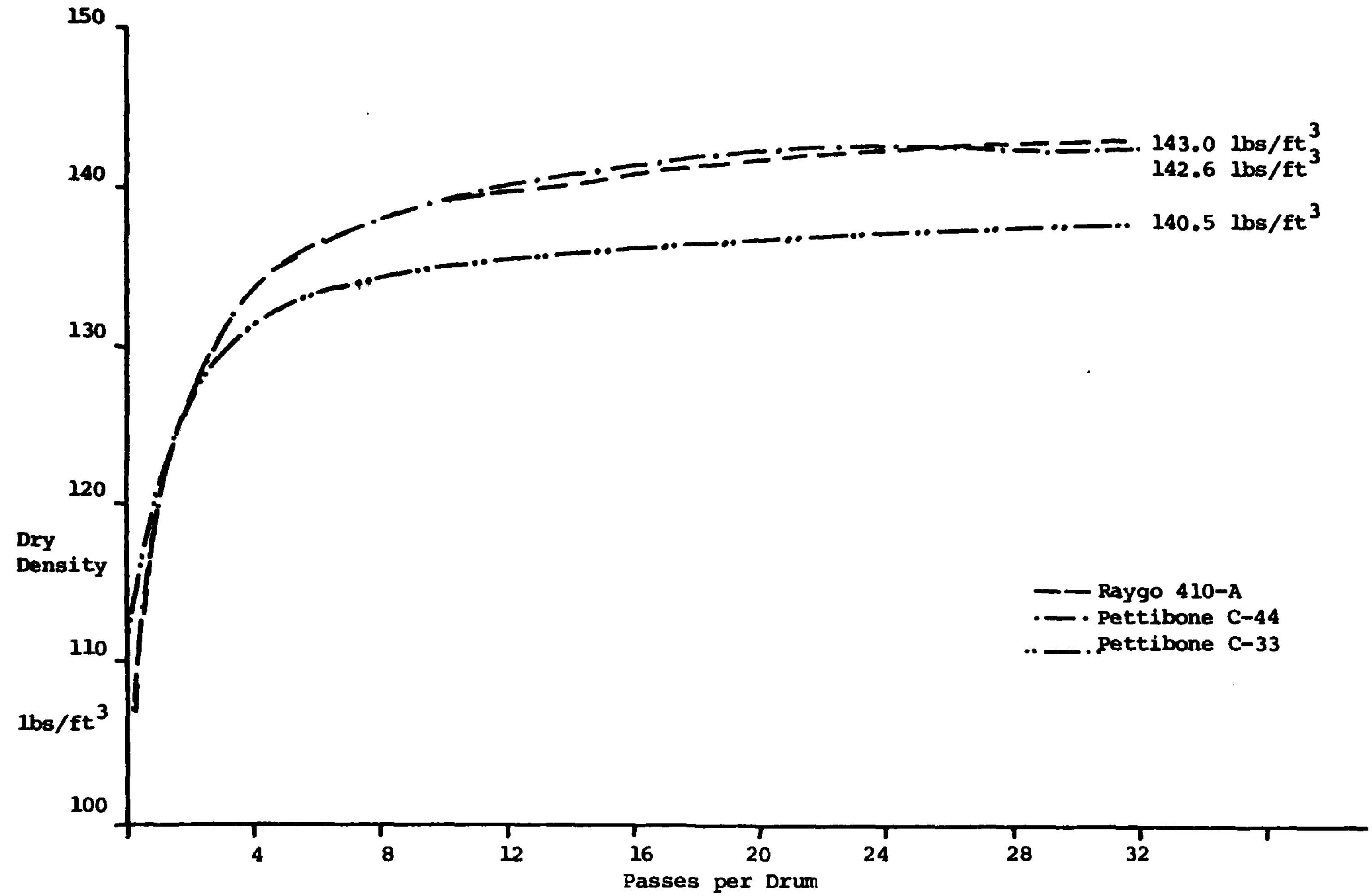


Figure 10. Compaction Curves.

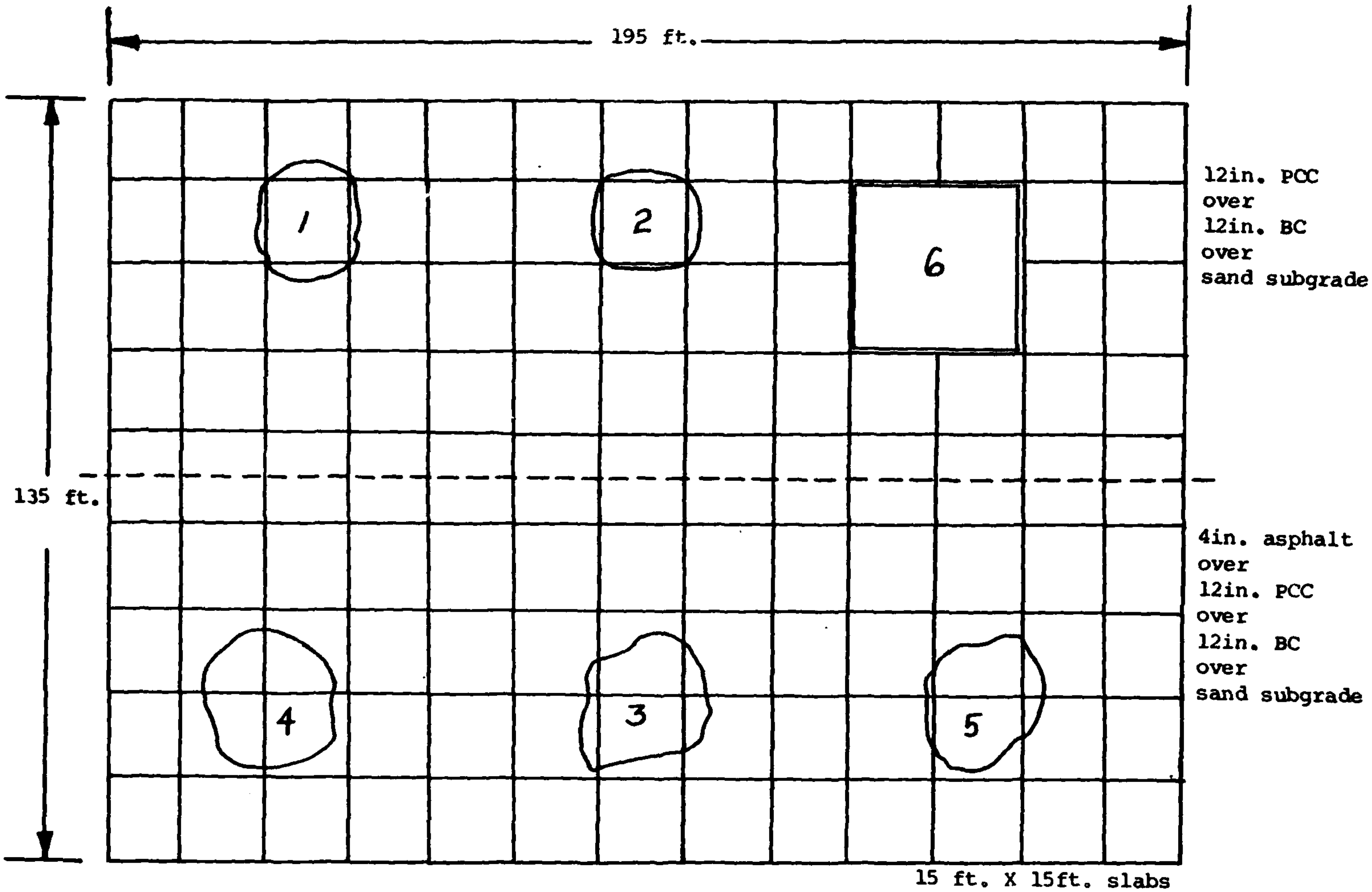


Figure 11. Explosive Crater Test Site Plan View.

PHASE II - CRATER REPAIR

Crater Preparation - The large dual drum compactor was tested on the #6 crater at the Explosive Crater Test Facility (see Figure 11). The crater was 30 feet in diameter square and originally filled with compacted crushed limestone. The limestone was scarified with a ripper-tooth equipped TD-15 dozer to a depth of 2.5 feet. The area was made to resemble a crater repaired with the crushed limestone technique just before the initial grading would take place.

Roller Operation. The Pettibone C-44, equipped with a strike-off blade was used to grade and compact the limestone in a single operation. The operator started with the blade on the concrete. As the compactor traversed the repair the operator attempted to smooth the limestone by raising and lowering the strike-off blade. This grading operation was attempted with the vibration both on and off. The Pettibone C-44 had vibration start/stop controls for each drum. The weights in the drums rotated opposite the drums' direction of travel. The drum controls allowed for the vibration of each drum to be started and stopped independently. The change in direction of the drum eccentric weight rotation was done to preclude bow waves from forming in front of the drums.

While the Pettibone C-44 compacted the crushed limestone satisfactorily, neither the AFESC operator or the Pettibone representative could get the repair smooth. The surface of the repair was plus or minus six inches in four to five feet. After over 1-1/2 hours of trying to grade the limestone, the effort was abandoned (Figure 12).

Results Analysis. The Pettibone C-44, equipped with a strike-off blade, while quite capable of pushing crushed limestone, was not successful in smoothing the repair. The difficulty came in trying to control the blade as the machine went up and down over the heaped limestone. The placement of the blade control on the floor of the operator's station, and its being foot-operated greatly reduced the amount of control the operator had over the blade. The other cause of the problem was the operator not being able to see either the position of the blade or the ground immediately in front of the drum (Figures 13-15). The independent drum controls posed no problem to machine operation and reduced the possibility of damage to the machine caused by having one of the drums vibrating on solid concrete, while the other drum is on the soil.

PHASE III - ROLLER PERFORMANCE AND DRUM CHANGE

Travel Test - The travel times of the Pettibone C-44 and the Raygo 410A to the Explosive Crater Test Facility were obtained to compare relative travel speeds of the two machines. The machines were operated by AFESC equipment operators. The course

Figure 12. Exploded Crater After Compaction and Grading

Figure 13. Pettibone C-44 Grading and Compacting

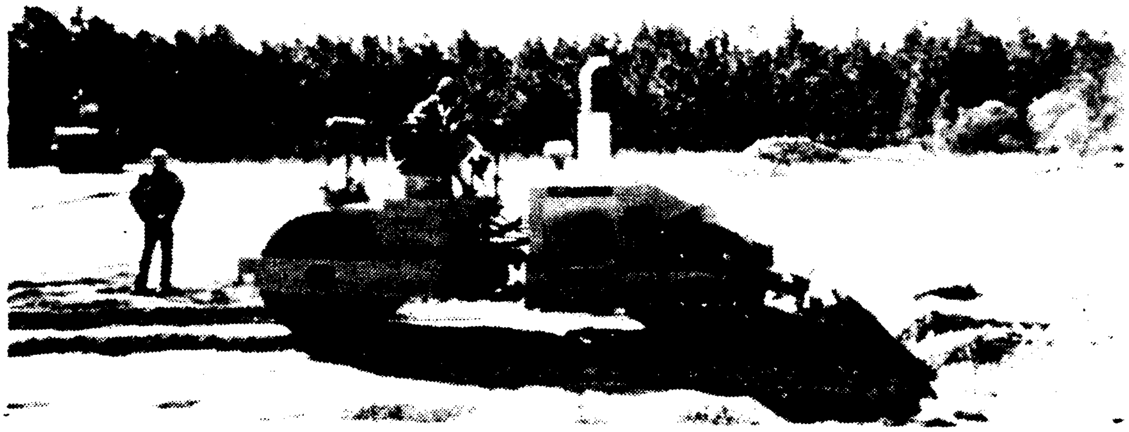


Figure 14. Pettibone C-44 Grading and Compacting

Figure 15. Pettibone C-44 Grading and Compacting

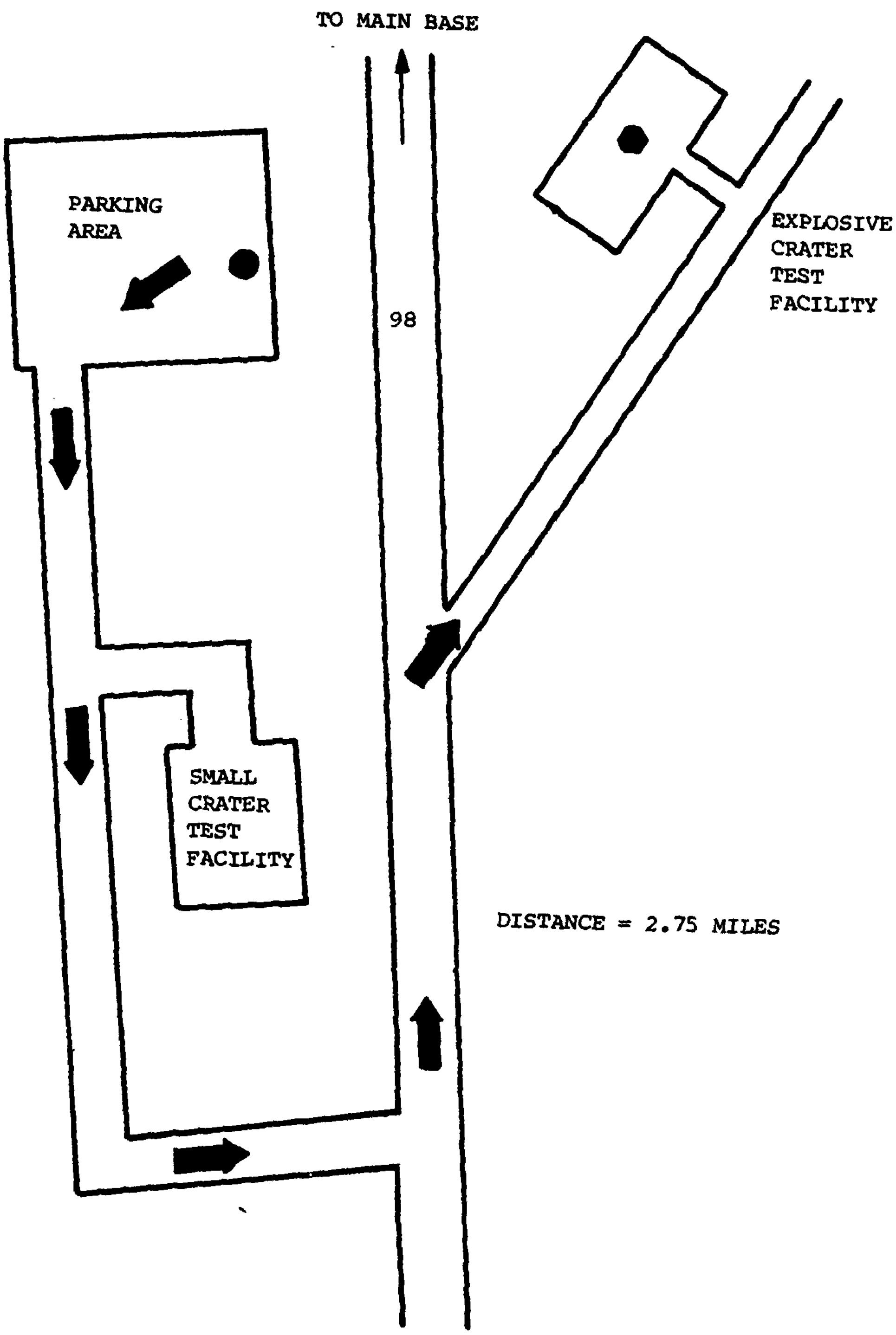


Figure 16. Course used for Travel Speed Test.

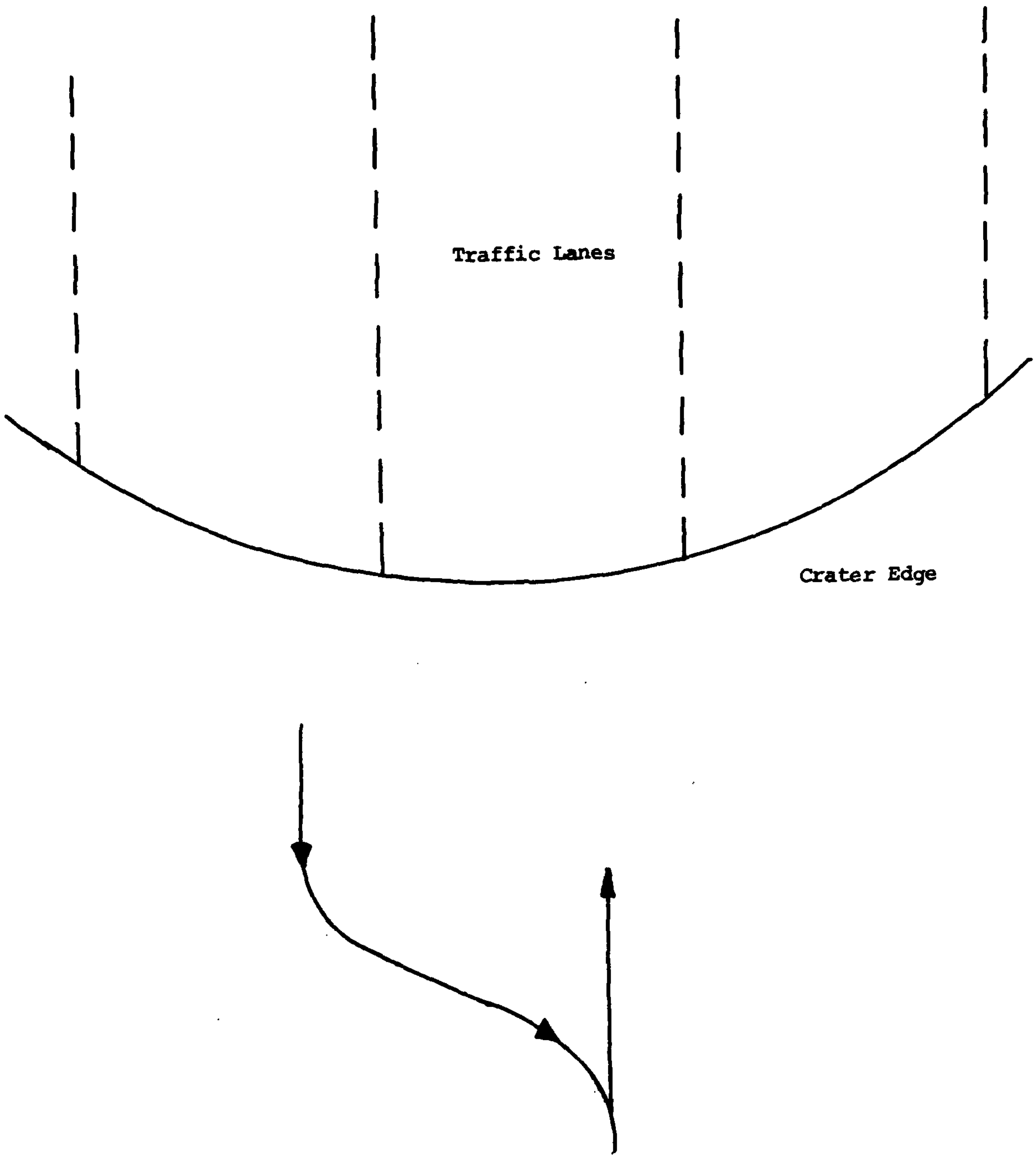
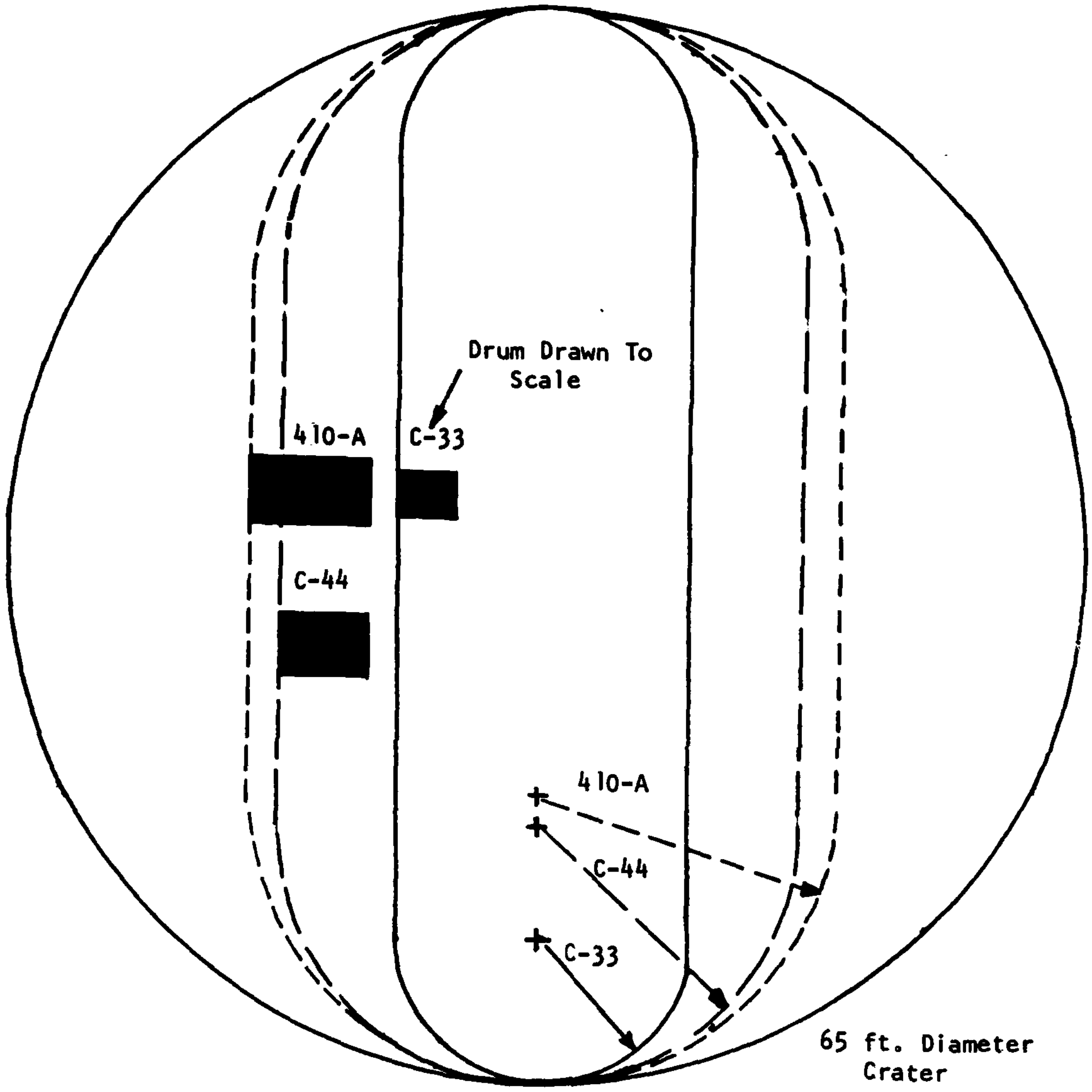


Figure 17. Lane Change Test.



	Outside Turning Radius	Drum Width
Pettibone C-33	11ft.10in.	42in.
Pettibone C-44	18ft.5in.	68in.
Raygo 410-A	20ft.3in.	84in.

Figure 18. Compactor Turning Radii.

TABLE 2. CRATER COMPACTION TIME ESTIMATES

	20 Ft Crater	65 Ft Crater
Raygo 410A	36 Min, 32 Sec	2 Hr, 25 Min, 44 Sec
Pettibone C-44	23 Min, 28 Sec	1 Hr, 10 Min, 48 Sec
Pettibone C-33	36 Min, 24 Sec	3 Hr, 54 Min, 56 Sec

length was 2.75 miles (Figure 16). The Raygo 410A took 30 minutes, 45 seconds, while the Pettibone took 46 minutes, 5 seconds.

Lane Change Test - The lane change test was done during the grading and compacting tests at the Explosive Crater Test Facility (Figure 17). The average time for lane change was 20 seconds for both machines. The time is an average of 14 lane changes for each machine.

Turning Radius - The turning radius of each machine was measured. To better compare the relative turning ability of each. Figure 18 shows the relative radii and drum sizes superimposed on a 65-foot diameter crater.

Crater Compaction Time Estimates - Lane change times, compacting speeds, and drum widths, can be used to estimate the time the machines would need to compact actual craters. The results are summarized in Table 2, and complete calculations appear in Appendix B. The estimates are for compaction times only and do not include any times for grading of the repair.

Drum Change - The ability to easily change drums on the Pettibone compactors is a unique feature claimed by the manufacturer. We changed the drums on the C-33 machine to judge the difficulty and the extent of the labor involved in the operation. Because the C-33 came equipped with pad drums; we changed these drums to smooth drums. The change was done in the maintenance building at the Engineering and Services Laboratory Test and Evaluation Site by the author, AFESC maintenance personnel and the Pettibone representative. The change required no special tools, however, an air wrench was used whenever possible to expedite the operation.

The drum change began at 1300 on Day 1. Two to four people worked on the machine for 4 hours that first day. They returned on the second day and worked for 6 more hours before completing the drum change. The Pettibone representative supervised and participated in the drum change. The procedure required the removal of the strike-off blade, the drum-drive hydraulic pumps, and the eccentric weight-drive hydraulic pumps, and the removal of the hydraulic lines and shim which held the drums in place in the frame. The change took 30-man hours over a two day period, although the job could have been done much faster if involved personnel had been experienced in the procedure. The design of the machine itself, however, while considerably simpler than other machines, made removal of the drums a tedious operation. The hydraulic lines were all solid, making their movement very difficult, and requiring bending of the tubes so that they would clear the drums. Because of the length of time it took to change the drums on the Pettibone C-33, it was decided not to change the drums on the Pettibone C-44.

Summary

The results of Phase III show that compaction time can be reduced by 50 to 60 percent, depending on the size of the crater, by using a dual-drum vibratory compactor instead of a single-drum vibratory compactor. The reduction in time is due to the following factors:

. The dual-drum compactor has 136 inches of drum on the ground compared to 84 inches of drum for the single-drum compactor, giving a 61 percent advantage in drum compaction surface area.

. A significant portion of the total compaction time is lane change time. A dual-drum compactor, with its tandem drums, requires approximately half as many lane changes for a given number of coverages compared to a single-drum compactor. The single-drum compactor, with its wider drum requires slightly fewer lanes than the dual-drum compactor, but on a 50-foot wide repair that means only one more lane for the dual-drum compactor.

The disadvantages of the dual-drum compactor are:

. The traction of a steel drum, although sufficient for RRR, is not as good as the rubber tires of the single-drum compactor.

. The Raygo 400A used in the RRR kits has a higher travel speed (17 mph) than dual-drum compactors which are commercially available today, with speeds ranging from 6 - 8 mph.

. The effort involved in changing the drums on the C-33 Pettibone did not support manufacturer's claims of quick-change capability. A true quick-change capability would be more versatile for use by base civil engineering squadron, however, the Pettibone machine has not been developed to that point.

SECTION IV

CONCLUSIONS

. Dual-drum vibratory compactors should be substituted for single-drum vibratory compactors of similar weight in the Rapid Runway Repair Equipment kits.

. Based on this evaluation and the results of past evaluations (Reference 1) vibratory compactors of less than 10-ton static weight do not have the capability to compact the large single lifts required for the current crushed limestone type repair procedure.

SECTION V

RECOMMENDATIONS

. The Air Force should procure dual-drum vibratory compactors for the RRR kits for use with the crushed limestone repair method.

. The Air Force should not include a requirement for quick change drums on its rollers.

. The Air Force should further study the question of required travel speed for its self-propelled compactors. Factors used in determining the travel speed should include:

a. Minimum time into a repair procedure before the compactors are actually required.

b. Maximum safe operating speed for compactors on smooth steel drums.

c. Anticipated maximum and average travel distances for compactors.

REFERENCES

1. Air Force Engineering Services Laboratory Technical Report 80-43, Evaluation of Vibratory Rollers for Bomb Damage Repair, by Kenneth J. Knox, August 1980.

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APPENDIX A

EQUIPMENT SPECIFICATIONS

	RAYGO 400-A	RAYGO 410-A with Drum Drive
PHYSICAL DIMENSIONS		
Overall Length	17 ft 3 in	17 ft 3 in
Width (overall and shipping)	7 ft 11-1/2 in	8 ft 8 in
Height (including muffler)	7 ft 2 in	7 ft 2 in
Shipping Weight (approx.)	20,000 lb	21,400 lb
Drum Diameter	59 in	59 in
Drum Length	84 in	84 in
Turning Radius (outside edge of drum)	20 ft 5 in	20 ft 5 in
Wheelbase	9 ft	9 ft
Curb Clearance (height)	16 in	16 in
PROPULSION SYSTEM		
Traction Wheel Drive	Hydrostatic Drive with 3-Speed Transmission	
Controls	Single Lever for Forward-Reverse Travel, Speed Control and Dynamic Braking	
Steering System	Hydraulic Power Steering - Articulated Type	
Braking	(1) Dynamic on hydrostatic drive	
Speed - 1st gear (F&R)	0 to 4.5	0 to 4.1
2nd gear (F&R)	0 to 9.0	0 to 6.2
3rd gear (F&R)	0 to 17.0	0 to 8.0
Tires	23.1 x 26 8-ply	23.1 x 26 8-ply
VIBRATION SYSTEM		
Hydraulic Direct Drive (no belts, no chains) Vibratory Drum	Yes	Yes
Dynamic Force	27,000 lb	27,000 lb
Variable Frequency	1100 to 150 VPM	1100 to 1500 VPM
Total Applied Force	47,000 lb	48,400 lb
Dead Stop Vibration Control	Yes	Yes
Reed Type Vibration Tachometer	yes	Yes
POWER UNIT		
Engine - Detroit Diesel	GM 3-53 (4-V) 88 h.p at 2500 RPM	GM 3-53 (4-V) 88 h.p. at 2500 RPM
Electrical System	12 volt	12 Volt
Muffler	Donaldson H.D.	Donaldson H.D.
Air Cleaner	Donaldson H.D. Dry Type	Donaldson H.D. Dry Type
Fuel Tank	50 Gallons	50 Gallons
Engine Disconnect Cluth	Yes	Yes
Hour Meter	Yes	Yes

PETTIBONE
C-44 SPECIFICATIONS

Shipping Weight	22,500 lb
Operating Weight	23,800 lb
Overall Length	199 in
Overall Width	80 in
Overall Height	104 in
Height (Top of railing)	84.50
Wheel Base	136 in
Curb Clearance	17 in
Artiuclated Steering $\pm 40°$	
Oscillation $\pm 15°$	
Outside Turning Radius	221 in
Drum Diameter	49.50
Drum Width	68 in
Frequency	2400VPM
Amplitude	(1) .0353 in
	(2) .0301 in
	(3) .0194 in
	(4) .0101 in
Centrifugal Force Per Durm	(1) 26,700 lb
	(2) 22,800 lb
	(3) 14,800 lb
	(4) 10,800 lb

Max Total Applied Force 75,400 lb
Applied force per linear inch - 553 PLI
Travel Speed - 0 to 6 mph
Gradeability - 35 percent with vibration
45 percent without vibration

Engine-Detroit Diesel	4-54 (115 HP)
Fuel Capacity	50 Gal
Hydraulic Oil Capacity	50 Gal
Water Capacity	200 Gal

Brakes - Service - Hydraulic Dynamic
Parking-Mechanical Disc on Drum

Electrical System - 12 v
Instrumentation: Tach/Hourmeter
Ammeter, Oil Pressure,
Water Temperature
Alternator, Neutral Light

PETTIBONE
C-33 SPECIFICATIONS

Shipping Weight	6,200 lb
Operating Weight	7,550 lb
Overall Length	126 in
Overall Width	46 in
Overall Height	
(with muffler)	91 in
(without muffler)	63 in
Wheelbase	87.25 in
Curb Clearance	10.5 in
Stering Angle	$\pm 40°$
Oscillation	$\mp 15°$
Outside Turning Radius	142 in
Drum Diameter	31 in
Drum Width	42 in
Freqency	3,200VPM
Amplitude	.015
Centrifugal Force per Drum	6,400
Total Applied Force	20,350 lb
Applied Force per Linear Inch	242 lb/in
Travel Speed	0-4.5 mph
Gradeability	35 percent, with vibration 40 percent, without vibration
Engine	Deutz Diesel Air Cooled F2L-91236 HP at 2500 RPM
Fuel Tank Capacity	37 gallon
Hydraulic Oil Capacity	32 gallon
Water Sprinklage Capacity	75 gallon
Battery - 12 volt	95 amp hour
Instrumentation	Tach/Hourmeter - Ammeter - Oil pressure alternator and Neutral indicator light

APPENDIX B

COMPACTION TIME CALCULATIONS

COMPACTION TIMES

- Raygo 410A
- Single Drum 84 in wide

20 second average for lane change time

Travel Speed = 4.4 ft/sec (average)

3 Lanes for 20 ft diameter crater - 11 lane change for 4 coverages

8 Lanes for 65 ft diameter crater - 31 lane change for 4 coverages

Travel Distance	Travel Time
20 ft crater - 240 ft	(240)/(4.4) = 54 sec
65 ft crater - 2080 ft	(2080)/(4.4) = 473 sec

4 coverages	TRAVEL TIME + LANE CHANGE TIME = COMPACTION TIME
20 ft crater	54 sec + 220 sec = 274 sec = 4 min, 34 sec
65 ft crater	473 sec + 620 sec = 1093 sec = 18 min, 13 sec

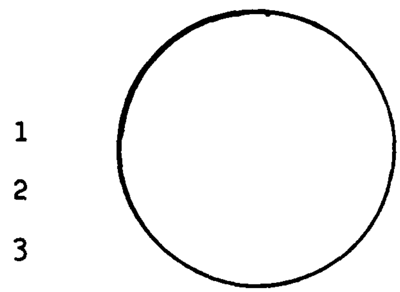
28 coverages	TRAVEL TIME + LANE CHANGE TIME = COMPACTION TIME
20 ft crater	378 sec + 1540 sec = 1918 sec = 31 min, 58 sec
65 ft crater	3311 sec + 4340 sec = 7651 sec = 2 hrs, 7 min, 31 sec

RAYGO 410A SINGLE DRUM VIBRATORY COMPACTOR

Single 84 ft Drum

Assume two crater sizes

1. 20 ft Diameter Crater



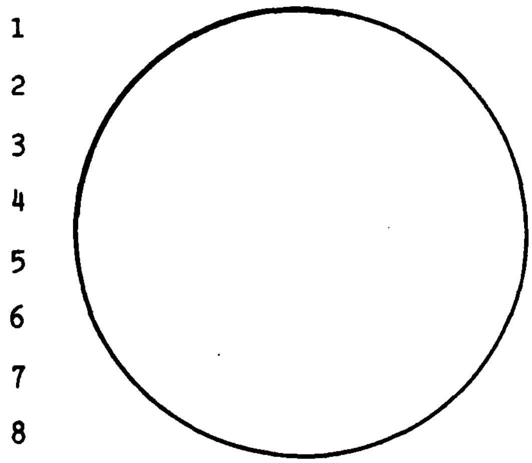
2.85 Lanes = 20 ft

4 coverages = 4 min, 34 sec

28 coverages = 31 min, 58 sec

Total = 36 min, 32 sec

2. 65 ft Diameter Crater



7.14 Lanes = 50 ft

4 cov = 18 min, 13 sec

28 cov = 2 hrs, 7 min, 31 sec

Total = 2 hrs, 25 min, 44 sec

Note: For 65 ft, diameter crater, only need to compact a 50 ft wide section.

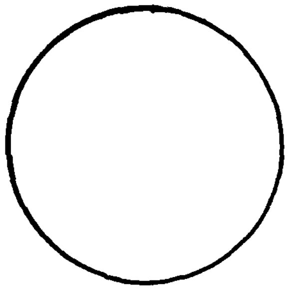
PETTIBONE C-44 DUAL DRUM VIBRATORY COMPACTOR

Dual 68 in Drums

Assume two crater sizes

1. 20 ft Diameter Crater

1
2
3
4



4 coverages - 2 min, 56 sec

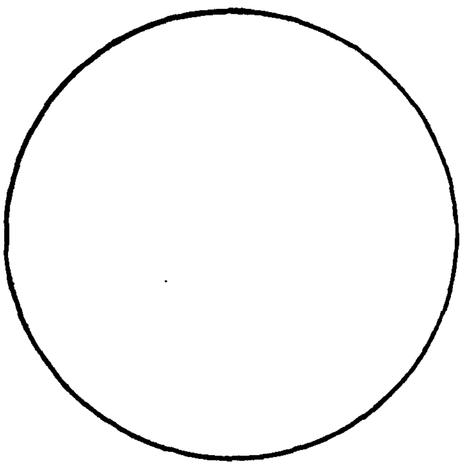
28 coverages - 20 min, 32 sec

Total = 23 min, 28 sec

3.53 Lanes = 20 ft

2. 65 ft Diameter Crater

1
2
3
4
5
6
7
8
9



4 coverages - 10 min, 6 sec

28 coverages - 1 hr, 10 min, 47 sec

Total = 1 hr, 20 min, 48 sec

8.82 Lanes = 50 ft

COMPACTION TIMES

- Pettibone C-44
- Dual 68 in Drums

20 second avenue lane change time
Travel Speed - 4.4 ft/sec (average)

4 lanes for 20 ft crater - 7 L.C. for 4 coverages

9 lanes for 65 ft crater - 17 L.C. for 4 coverages

Travel Distance	Travel Time
20 ft crater - 160 ft	160/4.4 = 36 sec
65 ft crater - 1170 ft	1170/4.4 = 266 sec

4 Coverages

	Travel Time + Lane Change Time = Compaction Time
20 ft crater	36 sec + 140 sec = 176 sec = 2 min, 56 sec
65 ft crater	266 sec + 340 sec = 606 sec = 10 min, 6 sec

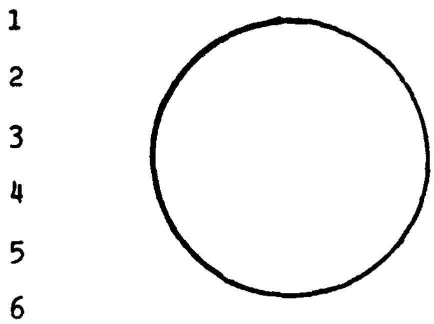
28 Coverages

	Travel Time + Lane Change Time = Compaction Time
20 ft crater	252 sec + 980 sec = 1232 sec = 20 min, 32 sec
65 ft crater	1862 sec + 2380 sec = 4242 sec = 1 hr, 10 min, 42 sec

PETTIBONE C-33 DUAL DRUM VIBRATORY ROLLER

- Dual 42 in Drums
- Assume Two Crater Sizes

1. 20 ft Diameter Crater



4 coverages
4 min, 33 sec

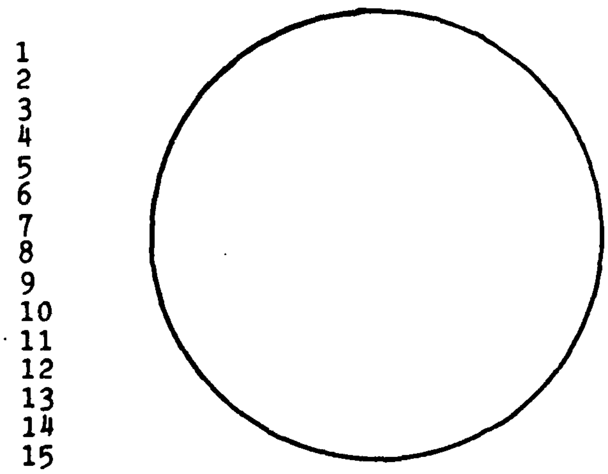
28 coverages
31 min, 51 sec

__Total__:

36 min, 24 sec

5.71 Lanes = 20 ft

2. 65 ft Diameter Crater



4 coverages
29 min, 22 sec

28 coverages

3 hrs, 25 min, 34 sec

__Total__:

3 hrs, 54 min, 56 sec

- 14.28 Lanes for = 50 ft

COMPACTION TIMES

- Pettibone C-33 Dual Drum Vib Compactor
- Double 42 ft Drums

20 second average for lane change (L.C.) time

Travel speed 4.4 ft/sec (average)

6 lanes for a 20 ft dia crater - 10 L.C. for 4 coverages

15 lanes for a 65 ft dia crater - 29 L.C. for 4 coverages

Travel Distance	Travel Time
20 ft crater - 240 ft	240 ft/4.4 = 13 sec
65 ft crater - 3900 ft	3900 ft/4.4 = 1182 sec

4 Coverages	Travel Time and Lane Change Time = Compaction Time
20 ft Crater	73 sec + 200 sec = 273 sec = 4 min, 33 sec
65 ft Crater	1182 sec + 580 sec = 1762 sec = 29 min 22 sec

28 Coverages	Travel Time + Lane Change Time = Compaction Time
20 ft Crater	511 sec + 1400 sec = 1911 sec = 31 min, 51 sec
65 ft Crater	8274 sec + 4060 sec = 12334 sec = 3 hrs, 25 min, 34 sec

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APPENDIX C

DENSITY AND MOISTURE DATA

DENSITY AND MOISTURE DATA

(Clay in pit had a California Bearing Ratio of 3.3 measured by pentrometer, average of 4 readings)

Pettibone
C-44

Coverage #	Probe Depth	Wet Density	Dry Density	Percent Moisture	Average Dry Density
0	BS	112.2	107.0	4.9	
4	12	138.1	132.9	3.9	
	4	138.1	132.8	4.0	
	12	140.2	134.5	4.2	
	4	141.0	135.3	4.3	133.9
8	12	143.0	137.0	4.4	
	4	145.6	139.4	4.4	
	12	139.7	133.6	4.5	
	4	145.6	139.9	4.1	137.5
12	12	145.0	138.5	4.7	
	4	146.2	139.7	4.6	
	12	146.9	141.6	3.7	
	4	145.2	139.8	3.9	139.9
16	12	148.3	142.6	4.0	
	4	146.6	140.6	4.3	
	12	141.9	140.0	4.9	
	4	147.6	140.9	4.3	141.0
20	12	149.9	144.1	4.1	
	4	149.2	143.1	4.3	
	12	146.1	140.3	4.2	
	4	148.1	142.2	4.2	142.4
24	12	149.4	144.0	3.7	
	4	147.8	141.9	4.1	
	12	147.3	141.6	4.1	
	4	148.0	142.0	4.2	142.4
28	12	147.4	147.4	4.7	
	4	149.4	149.4	4.5	
	12	148.2	148.2	4.6	
	4	150.5	150.5	4.7	142.2
32	12	147.0	147.0	4.0	
	4	147.3	147.3	3.9	
	12	145.9	145.9	3.7	
	4	152.2	152.2	3.9	142.6

Raygo
410-A

Coverage #	Probe Depth	Wet Density	Dry Density	Percent Moisture	Average Dry Density
0	BS				
	BS	112.2	107.0	4.9	
4	12	141.9	135.7	4.0	
	4	138.9	134.5	4.1	
	12	140.7	135.2	4.1	
	4	139.4	134.3	3.8	134.9
8	12	142.3	136.6	4.1	
	4	143.6	137.7	4.2	
	12	143.9	137.6	4.6	
	4	144.0	137.6	4.6	137.4
12	12	146.0	140.7	3.8	
	4	146.1	140.3	4.1	
	12	144.5	138.8	4.1	
	4	144.1	139..2	3.6	139.8
16	12	146.3	140.9	3.8	
	4	146.6	140.8	4.1	
	12	141.4	137.2	3.1	
	4	142.5	138.0	3.3	139.2
20	12	145.5	139.6	4.3	
	4	145.6	139.6	4.3	
	12	146.2	140.3	4.2	
	4	143.2	137.2	4.3	139.2
24	12	146.3	141.3	3.5	
	4	147.6	142.9	3.5	
	12	147.4	142.2	3.5	
	4	147.3	142.4	3.5	142.2
28	12	148.0	142.1	4.1	
	4	148.9	143.0	4.1	
	12	150.6	144.5	4.2	
	4	146.6	140.8	4.2	142.6
32	12	146.6	140.8	4.3	
	4	151.6	145.5	4.2	
	12	148.4	142.9	3.8	
	4	148.2	142.9	4.2	143.0

PETTIBONE
410-A

Coverage #	Probe Depth	Wet Density	Dry Density	Percent Moisture	Average Dry Density
0	BS	114.9	110.2	4.3	
	BS	118.2	113.7	4.0	111.9
4	12	137.5	132.5	3.8	
	4	138.9	134.0	3.7	
	12	138.6	133.8	3.6	
	4	137.6	132.8	3.6	133.3
8	12	136.0	131.0	3.8	
	4	140.1	135.3	3.5	
	12	139.2	133.7	4.1	
	4	135.7	130.1	4.3	132.5
12	12	139.0	133.9	3.8	
	4	144.0	138.7	3.9	
	12	142.0	136.5	4.0	
	4	142.6	137.0	4.1	136.5
16	12	141.0	135.8	3.8	
	4	142.2	137.4	3.5	
	12	137.5	132.7	3.6	
	4	142.2	137.2	3.6	135.8
20	12	142.6	137.3	3.8	
	4	145.6	139.7	4.1	
	12	140.5	135.2	4.0	
	4	141.4	136.0	4.0	137.1
24	12	138.9	134.0	3.7	
	4	141.9	136.9	3.6	
	12	142.4	136.4	4.4	
	4	148.2	143.0	3.6	137.6
28	12	142.3	137.6	3.4	
	4	142.4	137.5	3.6	
	12	140.0	135.0	3.7	
	4	144.4	139.3	3.7	137.4
32	12	145.6	140.3	3.7	
	4	146.3	140.8	3.9	
	12	144.0	138.6	3.9	
	4	147.4	142.3	3.6	140.5

APPENDIX D

COMMERCIALLY AVAILABLE DUAL-DRUM VIBRATORY COMPACTORS

COMPARISON OF SOME COMMERICALLY AVAILABLE DUAL DRUM COMPACTORS

	Raygo 400A	Raygo 410A	Bros VM-278	Galion VOS-2-66A	Pettibone C-44	Raygo 7204-A	Rex SP-1100	Tampo RS-166	Bomag BW 220A	Ferguson SP-266
Operating Weight (Approx, lbs)	21,000	22,400	25,000	20,420	21,800	25,000	25,500	20,000	26,940	20,430
Drum Width (in)	84	84	78/156	66/132	68/136	72/144	80/160	66/132	80/160	66/132
Drum Diameter (in)	59	59	54	48	49.5	48	48	48	48	48
Static lbs/in of Drum Width	131	133	160	155	160	173	159	166	168	155
Travel Speed (mph)	17	8	7	8	6	8	7.5	6.75	6	6
Frequency Range (VPM)	11-1500	11-1500	2300	11-2400	2400	12-2300	2-2400	22-2400	17-2400	12-2500
Rated Dynamic Force (per drum) (lbs)	0-27,000	0-27,000	12,500-21,000	9,500-30,000	10,800-26,700	0-32,000	6,800-30,000	9,736-16,000	4,400-30,000	17,500-35,000
Total Applied Force (per drum)	10,500 47,000	11,200-48,400	25,000 33,500	18,215-38,715	21,700-37,600	12,500-44,500	19,550-42,750	19,736-26,000	17,870-43,270	27,715-45,215
Turning Radius (in)	245	245	287.5	247	221	223	286	208	266	241.5
Horsepower (SAE Net)	88	88	155	125	116	115	136	80	150	102

D

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